HIGH PERFORMANCE INSULATIONS AND FUTURE HOUSING SYSTEMS

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ABSTRACT

This paper excerpts work in progress within a United States Department of Energy sponsored research program. In this work, design studies establish scenarios of energy efficient housing systems for the year 2030 based on the anticipated development of materials and technologies currently in basic research, development and early commercialization. Of the scenarios explored, this paper summarizes portions of the Cool Climate Scenario developed for a heating dominated climate (Minnesota). This scenario is derived from current materials research underway in thin, high performance insulations, phase changing finishes, wood composite materials, space conditioning appliances and process research underway in design process computing and manufacturing. Of these only the insulations related sections are the subject of this paper.

1. FUTURES RESEARCH FOR ENERGY EFFICIENCY IN HOUSING

Housing systems integrate a matrix of processes and products that have been, and continue to be, in a slow but continuous process of refinement and evolution. For energy efficiency to be a welcome participant in this evolution, researchers in the area must be prepared with visions of goals and opportunities for energy conservation that anticipate change in housing design and production, wherever it may come.

The Design for Energy Efficiency task area of the U.S.. Department of Energy sponsored Energy Efficient Industrialized Housing Research Program was established to anticipate such opportunities for a future generation of energy efficient housing — nominally the year 2030. This work sought to establish visions of cost effective energy efficiency on a 'whole house' basis, seeking points of opportunity where industrialized products and processes could contribute to housing that is well-designed, energy efficient and cost less to purchase and operate.

This work was conceived and organized to recognize that:

- There are multiple futures to anticipate. Change in the design and construction of housing will emerge from a wide variety of social, political, economic and technological forces.
- Energy conservation opportunities are not exclusively technology based. Many are a part of other decisions and processes distributed throughout a housing delivery process
- Change takes time. Two generations may pass between initial research and commercial diffusion in mature established industries such as housing

2. AN R-50 ENVELOPE ?

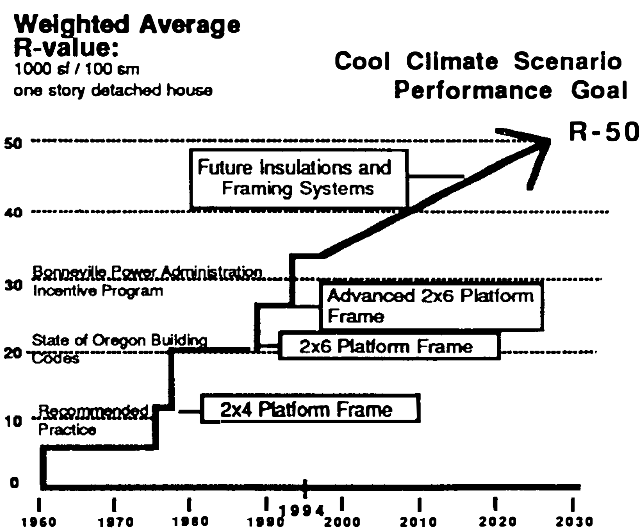

Fig. 1.
Envelope Average R-Values, 1960 - 2030

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One illustrative example of this process is the opportunity high performance insulations (compact vacuum panels, powder evacuated panels, gas-filled panels and aerogel panels, for example) currently in development to replace CFC-based materials and processes in the refrigeration industry may bring to the evolution of envelope construction in housing. Looking backward, code-mandated construction practice has roughly doubled the thermal resistance of wood frame construction in about 20 years of innovation and development. That construction system, as we know it, is more or less now at its practical limit for thermal resistance. Figure 2 compares the theoretical thermal resistance of houses built to residential construction codes in Oregon from approximately R - 12 overall in 1974 to R - 25 overall in 1994. If a comparable rate of improvement is sought over the next 20 or 30 years (as do some European countries — Switzerland, for example), a different generation of envelope materials and construction techniques are likely to be necessary.

2.1 1970 Envelope Performance

Envelope materials prior to the oil embargo and the advent of energy requirements in building codes in 1974 yielded approximately R-12 to 15 overall for houses built to recommended practice of American Institute of Architects.

Walls:	2 x 4 wood frame with R-7 insulation
Roofs:	R-9
Floors:	R-7 over crawl spaces
Windows:	Single glazed wood and aluminum sash of approximately R- 1
Doors:	Uninsulated wood slabs and frames without weatherstripping R- 2.5
Air tightness:	Approximately 1.0 ACH

2.2 1994 Envelope Performance

Twenty years after the first energy requirements in building codes, new houses in those jurisdictions requiring the most energy efficient construction are approximately R-25 overall, very close to the practical limit of platform frame construction as we know it.

Walls:	2 x 6 wood frame with R- 26 insulation
Roofs:	Mostly truss construction with R-38 insulation
Floors:	Insulated wood frame (where over a crawl space) of R- 25
Windows:	Double glazing and thermally broken wood or aluminum sashes of R- 2.5
Doors:	Insulated steel slabs and weather stripped frames.
Air tightness:	Approximately 0.35 ACH

2.3 2030 Envelope Performance

A comparable rate of performance improvement over the next 30 years would yield an envelope of approximately R-50 overall. Such an envelope would likely be manufactured in panels (Figure 2) of insulations described in Section 3 and manufactured with materials, processes and tools researched in the larger program but outside the scope of this paper. This panel might be used in wall, floor and roof applications (see enclosure schematic Figure 3) to the following performance specifications:

- Insulated envelope components of approximately R-25 per inch of thickness
- Windows overall R-10
- Doors and frames overall R-25
- Thermal storage via phase changing interior finishes
- Lateral stability and resistance to shear loads of 400 lb. / l.f.

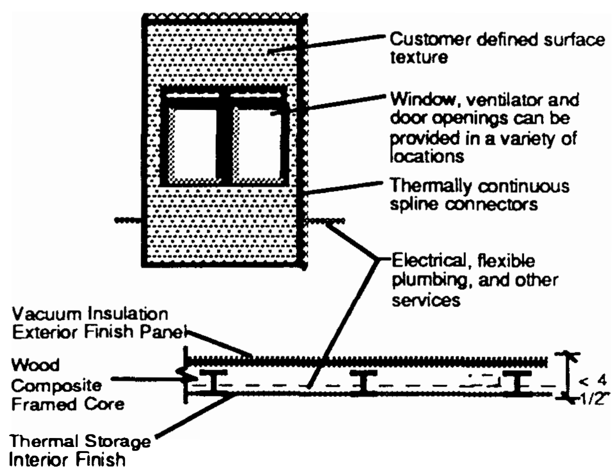

Fig. 2.
Schematic of a panel derived from thin insulations explored in the Cool Climate Scenario

A panel of this type offers the opportunity of a thin, stressed skin type envelope of light weight, high thermal performance, air tightness, and structural efficiency. At the exterior is a rigid sheathing and finish layer encapsulating one of the thin insulation materials described in greater detail in Section 3. At the interior is an interior sheathing and finish layer incorporating a phase changing material. Between, a series are laminated wood composite ribs. Windows and doors can be accommodated in a variety of locations and sizes.

3. THE COOL CLIMATE SCENARIO

Of the several scenarios explored in the Design for Energy Efficiency task, one, the Cool Climate Scenario explores the opportunity presented by this potential future generation of panelized envelope systems. Overall this scenario calls for a high performance envelope able to meet the wide range of design and style variation associated with small scattered development sites in new and infill situations and median cost markets.

Among the envelope related performance goals of this scenario are:

A zero net energy budget:
- reduce space conditioning loads by approximately 85% over Long Term Super Good Cents standards for thermal resistance and infiltration
- reduce infiltration rates to less than 0.15 ACH
- meet 85% of space conditioning loads with heat recovery based systems
- balance electrical power drawn with household photovoltaic generated returned to utility
- reduce and distribute utility peak loads to off-peak hours (with phase changing interior finishes)

Conservation of raw materials:
- decrease wood resource based materials by about one-half over contemporary practice
- reduce material waste in production by about one-half over contemporary practice

Cost:
- affordable in a median income market
- reduce development portion (land, infrastructure, design and engineering processes etc.) portion of whole house cost by 15%
- reduce mechanical systems portion of construction costs by approximately 50%
- eliminate use-based utility costs

Flexibility in site design:
- achieve minimum densities of 8 detached houses per acre
- reduce structure and envelope portion of gross floor area by approximately 50%
- adapt to the diversity of site configurations, plan types and architectural styles associated with infill and scattered site development
- mitigate the limitations of orientation associated with small or constrained sites
- reduce site impact of construction processes, utilities and paving

Flexibility in house design
- accommodate significant variation in house design in areas of size, configuration, fenestration, finish and architectural style
- mitigate the effect of owner design preferences (glazing areas and skin to volume ratios)
- complete flexibility in internal layout in areas of room size, configuration and opening location
- reduce size and capacity of space conditioning appliances, mechanical and distribution systems
- permit remodeling and expansion by owners with low-technology tools and skills

Simplification of construction:
- reduce site labor requirements by half
- reduce foundation system preparation and materials
- simplify assembly, disassembly and recycling of construction materials and components

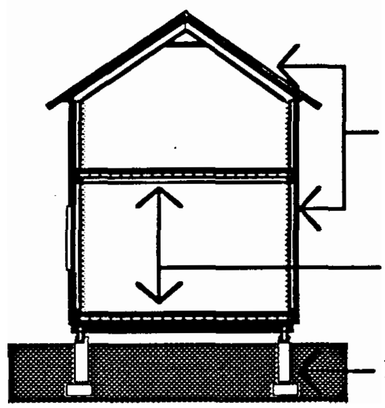

Fig. 3.
Schematic section of the envelope system of the Cool Climate Scenario

The envelope anticipated in this scenario (Figure 3) uses the high strength of fiber-based wood composite materials (parallel strand lumbers, laminated veneer lumbers and fiber composite sheets, for example) intended to replace tree sawn dimensional lumber to create a light, material efficient assembly of very high thermal resistance — approximately R- 50 overall in the version illustrated above.

Figure 4 compares the whole house energy performance of a house of approximately 1000 square feet designed to Long Term Good Cents standards (the reference case — approximately R-49 roof, R-26 walls, R-30 floors, R-2.86 windows and R-5.26 doors) and the same house (the illustration case) designed to envelope performance goals investigated in the Cool Climate Scenario. In this example, the illustration case also anticipates higher efficiency appliances over and above envelope improvements.

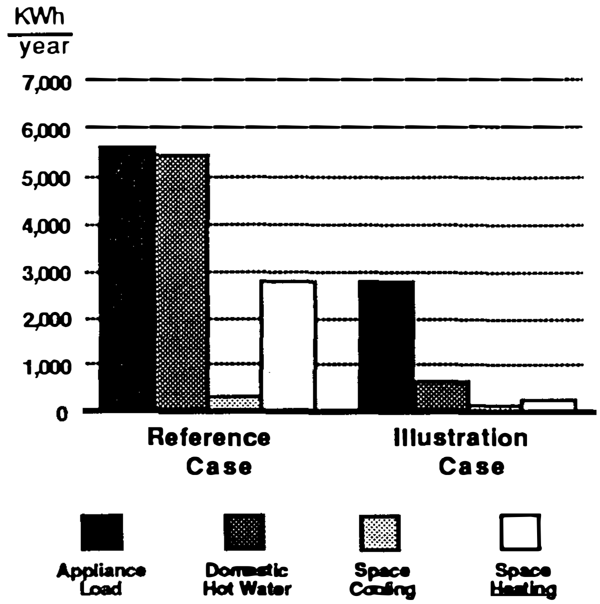

Fig. 4.
Cool Climate Scenario Average Annual Energy Load for a 1000 Square Foot House in Minneapolis. (Calpas3 analyses)

4. THE INSULATIONS

Among the most promising examples in the insulations area are:

3.1 Gas-filled panels

Research group: Lawrence Berkeley National Laboratories

Description: A low thermal conductivity gas encapsulated within a sealed flexible panel. Low-emissivity baffles suppress convective, conductive and radiant heat transfer. Panels may be manufactured for on-site "inflation"

Fill material: Air, Argon or Krypton.

Envelope: Polyvinyl alcohol or ethylene vinyl alcohol films.

Thickness: 1.0 in. typically

Dimensional Limitations: Undetermined

Weight: 0.4 lb. / cu. ft.

Target R- values: Air - R 5.2 / in.
Argon - R 8.0 / in.
Krypton - R 15.0 / in.

Manufacturing Cost Target: Air - $ 0.50 - 1.00 / sq. ft.
Argon - $ 0.80 - 1.50 / sq. ft.
Krypton - $ 3.30 / sq. ft.

Anticipated Housing Application: Stud wall cavity. Site or factory based.

3.2 Powder-evacuated panels

Research group: Oak Ridge National Laboratories

Description: Air vacuum and a compacted silica based powder sealed in a multi-layer flexible gas barrier. Insulation values are from combination of the thermal resistance properties of an air vacuum and thermal conductance properties of the microstructure of a compacted powder.

Fill material: Fumed silica, silica powder.

Envelope: Polyvinyl alcohol films.

Thickness: 0.5 in. typically

Dimensional Limitations: Undetermined

Weight: 0.1 lb. / cu. ft.

Vacuum: .001 - .002 atm

Target R- values: R 40.0 / in.

Manufacturing Cost Target: $ 0.40 / sq. ft.

Anticipated Housing Application: Factory based construction.

3.3 Compact vacuum insulation

Research group:	National Renewable Energy Laboratories
Description:	Air vacuum encapsulated within a steel envelope. Atmospheric pressure is resisted by glass sphere spacers and metal panels. Greater R-values can be achieved by stacking layers of units.
Fill material:	Vacuum and glass spacers.
Envelope:	8 mil. steel
Thickness:	0.1 in. in prototype
Prototype Dimensions:	8' - 0" x 16' - 0"
Vacuum:	.001 - .002 atm
Target R- values:	R 25.0 / in.
Manufacturing Cost Target:	$ 2.00 / sq. ft.
Anticipated Housing Application:	Manufactured in a laminated composite panel. Other applications include sodium sulphur batteries, catalytic converters, refrigeration units and storage tanks.

3.4 Aerogel insulation
Lawrence Berkeley National Laboratories

Description:	Fine micro-structure of low density, open pore solid gel inhibits radiant and conductive heat transfer. Insulation performance triples in evacuated space.
Fill material:	Silica dioxide.
Envelope:	Composite polymer film.
Thickness:	0.1 in. in prototype
Prototype Dimensions:	8' - 0" x 16' - 0"
Weight:	5.0 lb.. / cu. ft.
Vacuum:	.01 atm
Target R- values:	R 40.0 / in.
Manufacturing Cost Target:	$ 1.00 - 2.00 / sq. ft.
Anticipated Housing Application:	Manufactured in a laminated composite panel adaptable to a variety of panelized and retro-fit applications.

4. ISSUES GUIDING A RESEARCH AGENDA

Future systems and technologies envisioned by the scenarios explored in the Design for Energy Efficiency Task of the Energy Efficient Industrialized Housing Research Program can offer higher energy performance, better resource utilization and lower cost to homeowners. As research is initiated to realize these opportunities it must acknowledge in its concept and design that significant non-technical barriers must be overcome in parallel. Among these are the following examples:

4.1 Housing innovation will always be first cost sensitive.

Energy conservation measures have historically increased the first cost of design, materials and installation in housing. Although the economics of these energy conserving materials and technologies have been favorable on long-term and life cycle bases, housing consumers are very sensitive to first cost considerations. The affordability gap is increasing for many households in the United States. As a consequence, home ownership rates are in decline and fewer households are projected to be able to sustain the financial burden of homeownership in the future unless it declines in cost. Research anticipated to interest housing consumers in energy conserving technologies must accept first cost as a fundamental performance parameter.

4.2 The building industry and its market are traditionally risk-averse.

The materials and methods of housing construction have evolved over a sustained process of practice and field experience. In the absence of evidence of consumer interest and demand, builders and the manufacturers that supply them are less likely to assume extraordinary risk they associate with the adoption of new products and innovations. Both consumer and industry audiences are unlikely to be convinced in the absence of demonstrations and research results designed to stimulate their interest and awareness.

Many of the systems and technologies likely to be a part of housing in the future are already in phases of research and development. Some could be commercially available by the end of this decade. Others may not realize their commercial potential until 2030 or perhaps beyond. Progress toward those that require long development times must deliver interim products along the way to justify the investment of sponsors as well to stimulate the interest of consumers and confidence of industry.

4.3 The research required demands sponsor cooperation.

The nature of research needed to improve energy conservation in housing into the next century is changing. As the house becomes a more complex, better performing, lower cost product, its design will aggregate components into more sophisticated systems of fewer, higher-value, more integrated parts. The performance and boundaries between one part, component or system and another are increasingly less distinct and their performance attributes more interdependent.

Research needed to realize the performance of envelope systems anticipated in the Cool Climate Scenario, for example, is simultaneously technical, design, manufacturing and economic in focua. Progress toward that vision will hinge on successful development of construction components that economically integrate the thinness and energy performance of thin insulations and phase changing finishes with the engineering efficiencies of wood composite materials and the manufacturing and assembly efficiencies of a highly skilled construction sector. For example, the vacuums and encapsulated gases common to the insulation materials must be manufactured with other construction materials and processes able to protect them during manufacture and installation.

And, new envelope systems must ultimately deliver a whole house that first cost competitive with the systems they displace. In this example, cost premiums associated with these higher performing technologies may ultimately be off-set with research that reduces building service requirements and expedites design, manufacturing and field assembly processes.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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Information and specifications for the future insulations cited in this report were gained from unpublished information and telephone interviews with the following during the summer and fall of 1993.

Ron Graves, Oak Ridge National Laboratories, Oak Ridge, TN

Brent Griffith, Lawrence Berkeley National Laboratories, Berkeley, CA

Tom Potter, National Renewable Energy Laboratories, Golden, CO